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A TUTORIAL FOR PERFORMING A RADIOGRAPHIC EXAMINATION

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14. ABSTRACT
This report is a detailed tutorial of performing a simple radiographic examination from start to finish. The intended purpose of this report is to assist technicians and scientists in applying a formal and systematic process in setting up, developing, documenting, and performing industrial radiography. The examples provided within this report are specific to the inspection of munition and/or weapon systems the U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, inspects on a regular basis. The fundamental components that will be reviewed include: (1) personnel qualifications, (2) understanding part specifications, (3) equipment selection, (4) developing a technique, (5) verifying image quality, and (6) organizing proper documentation. Each section will provide an in-depth understanding and illustration of the content and tangible functions that are necessary to complete an entire nondestructive test.

15. SUBJECT TERMS
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INTRODUCTION: PERSONNEL QUALIFICATIONS

Developed by the American Society of Testing and Materials (ASTM), the overarching radiographic standard that is typically adhered to within the United States is ASTM E 1742 (ref. 1). This standard provides an overview on what goes into performing an inspection but does not specifically show how to do an inspection. There are substantially more references that apply to radiography, but only the major specifications that apply to a general nondestructive testing (NDT) practitioner will be discussed throughout this report.

Having properly qualified and certified personnel present is the first component that needs to be in place when starting up an NDT inspection. In order to reliably perform an NDT method (such as radiography) the practitioners need to have adequate credentials, background, training, and experience. As far as personnel goes, there are several nationally recognized standards that specify how to qualify or certify NDT personnel. The three most prevalent are: (1) the American Society of Nondestructive Testing document SNT-TC-1A, (2) the National Aerospace Standard (NAS) document NAS-410, and (3) the International Standards Organization (ISO) document ISO-9712 (refs. 2 through 4). These standards outline the minimum requirements that a NDT practitioner should meet prior to being classified as qualified. A qualified individual is one that has received adequate classroom training, acquired sufficient hands-on experience in the method, has the appropriate time in practice, met the physical requirements, and passed multiple examinations that show one’s competency.

Within the NDT field, there are generally three levels of qualification: I, II, and III. Each level is associated with a certain amount of expertise, abilities, and responsibilities. A level III is generally a practitioner that has achieved above the minimum requirements and is fully functioning to work as a team lead and/or operate independently. A certified NDT practitioner is one who is formally recognized by their employer to have met the minimum qualifications and represents the company. This report is written from the perspective that the sample inspections are being performed by a qualified/certified level III. If the inspection practices within this report were reviewed or audited, all of the qualification and certification records would be assessed to determine the selected personnel standard is being abided by. This report is intended to be specific toward the direct application. Therefore, the content for acceptable personnel documentation will not be reviewed.

PART SPECIFICATION

With the correct staffing in place, the most important document in which to begin an inspection is the requirements document. In some cases, this may be a simple form provided by the customer for the purpose of the inspection and what criteria to inspect for. Within the U.S. Army, some inspection sites are provided with a depot level requirements document that specifically defines the entire inspection and can universally be used by anyone that needs to accomplish a specific examination. In other situations, the customer provides no starting point and the inspection criteria has to be developed by the radiographic site with collective input from various scientists and engineers. In this report, it is assumed that a part specification is provided that lists what criteria needs to be detected and measured and how parts are dispositioned between acceptable and rejectable pieces. Table 1 provides an example of a part specification. It is a very basic and straightforward specification for a cylindrical cast billet of explosives. These requirements are the starting baseline for what needs to be achieved or detected to assure the parts are being inspected correctly and will function as intended when used or put into service.

Table 1
Basic part specification example

Basic part specifications
Part dimensions
2-in. diameter
2-in. tall
Part material(s)
Solid cast billet of trinitrotoluene (TNT); cylindrical
ρ (density) = 1.65 g/mL
Defective conditions/Rejection criteria
Piping not allowed anywhere within the cast
Foaming or conglomeration of cavities not allowed anywhere within the cast
Cavities will not exceed 1.5 mm (0.059 in.)
Defects are not allowed within the top 1/3 of the cast
Crack width cannot exceed 2 mm (0.079 in.)
Additional requirements
Minimum contrast sensitivity of 2%

EQUIPMENT SELECTION

Overview

With the criteria of the part defined, the radiographer has to have previous knowledge of what kind of equipment is necessary or required in order to achieve the correct image quality. The practitioner also has to know several other factors to accurately determine which equipment best meets the intent of the inspection. The primary variable is the physical construction of the part. The size, shape, materials, and overall configuration have to be assessed since these characteristics will impact the inspection settings and technique. The part will essentially dictate many variables including: (1) what photon energy range is needed, (2) the total exposure time, (3) whether or not collimation is necessary, (4) the size of the field of view, (5) whether or not scatter reducers are needed, (6) whether or not inline beam filtration is needed, (7) orientation with regard to the source and detector, and so forth. Other factors that will vary the image quality are photon source (x-ray, gamma) characteristics and the image media being used. In the examples provided within this report, it's assumed all radiation sources are x-ray based. At this point, the practitioner should logically start at one piece of the critical equipment, determine what type is needed for the inspection criteria, and move on to the next.

Geometry

Starting with the x-ray source, the type necessary to meet the part specifications in table 1 needs to be established. Then, a determination should be made as to whether or not high energy (1 MeV or greater) is needed for more penetration, and what spot size would be an acceptable. There are two methods to determine the source: (1) empirical by doing a test and check method, and (2) doing preliminary calculations to narrow the options. The empirical method is nothing more than taking a best guess on the setup, taking a quick test shot with some unknown settings, and continuing the process until acceptable results occur. This method can be effective for basic parts, but can be unreliable when the part is complex or the inspection criteria is very strict. Using basic calculations, the equipment selection and setup time can be reduced. The first step in quantitatively assessing the equipment needed is to determine the largest effective spot size that can be used while still meeting the spatial requirements. Equation 1 provides the method to determine the allowable geometric unsharpness when not using magnification. Equation 2 is used when physical magnification is used.

$$Geometric\ unsharpness\ (Ug) = \frac{focal\ spot\ size\ (f) * part\ thickness\ (t)}{source\ to\ object\ distance\ (SOD)} \tag{1}$$

$$U_g = \frac{focal\ spot\ size\ (f) * source\ to\ object\ distance\ (SOD)}{object\ to\ detector\ distance\ (ODD)}$$

$$U_g = f(Magnification\ (M) - 1) \tag{2}$$

The minimum values for the unsharpness, source to object distance (SOD), object to detector distance (ODD), focal spot size, or source to detector distance (SDD) can be determined depending on which variables are fixed, based on the equipment available, and which ones have to be adjusted to meet the inspection requirements. Table 2 provides comparative values of the unsharpness for the TNT billet with several different setups using four commonly available spot sizes in commercial industrial x-ray sources. The first setup for each of the four spot sizes represents a physical layout where the billet is completely against the image media. The calculation of magnification is provided in equation 3. The second setup uses the same SDD, decreases the SOD or ODD, and increases the magnification by a factor of 2x. The third setup is identical to the first, except for a decrease in the SDD from 1828.8 mm (6 ft) to 1219.2 mm (4 ft). Out of all twelve potential setups, only two would not meet the minimum requirement for the 2% contrast sensitivity limit, assuming a change of 2% in the part thickness is equivalent to that limit. When the unsharpness exceeds the 2% limit, that level of thickness change or a void of that size would not be detected or discernible within the radiograph.

Table 2
A comparison of three different physical setups using four different spot sizes for the 2-in. diameter TNT billet

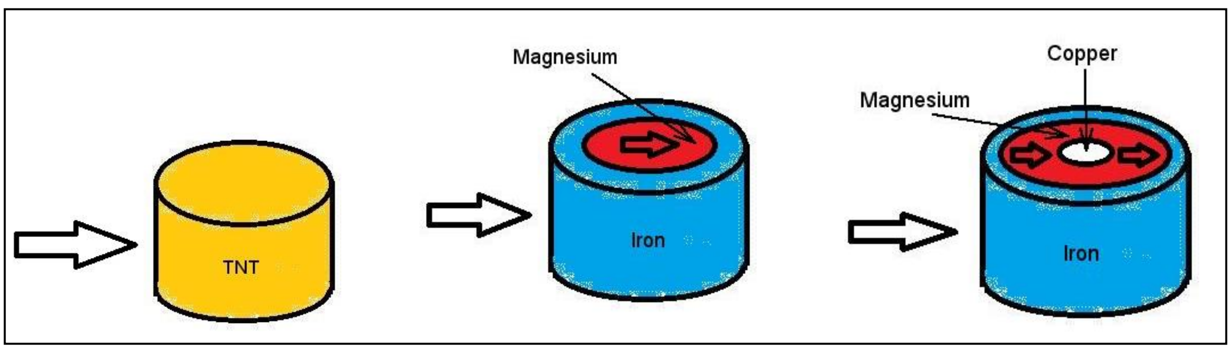
	Comparable setups											
Part thickness (mm)	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8
Spot size (mm)	6.3	3.0	1.0	0.2	6.3	3.0	1.0	0.2	6.3	3.0	1.0	0.2
SOD (mm)	1778.0	1778.0	1778.0	1778.0	914.4	914.4	914.4	914.4	1168.4	1168.4	1168.4	1168.4
ODD (mm)	50.8	50.8	50.8	50.8	914.4	914.4	914.4	914.4	50.8	50.8	50.8	50.8
SDD (mm)	1828.8	1828.8	1828.8	1828.8	1828.8	1828.8	1828.8	1828.8	1219.2	1219.2	1219.2	1219.2
Unsharpness (mm)	0.175	0.083	0.028	0.006	6.300	3.000	1.000	0.200	0.263	0.125	0.042	0.008
Magnification (x)	1.056	1.056	1.056	1.056	2.000	2.000	2.000	2.000	1.083	1.083	1.083	1.083
2% part thickness (mm)	1.016	1.016	1.016	1.016	1.016	1.016	1.016	1.016	1.016	1.016	1.016	1.016
Unsharpness < 2%	yes	yes	yes	yes	no	no	yes	yes	yes	yes	yes	yes

$$Magnification = \frac{SDD}{SOD} \tag{3}$$

The requirement is set at a 2% contrast sensitivity value since the smallest dimensional tolerance allowed for a given defective condition is 1.5 mm for cavities. This relates to the smallest indication that needs to be detected. In this case, the U.S. Army generally uses the hole or plaque type image quality indicators (IQI). These IQI typically have measureable holes that achieve 1, 2, and 4% in contrast sensitivity. These measurements of image quality will be discussed in a later section within this report. The takeaway is a 4% change in thickness, which would be 2.03 mm (which is larger than the 1.5-mm criteria). On the other hand, a 1% change means a void or thickness change of 0.51 mm could potentially be detected. The 2% requirement is the minimum since it's the closest to and under the minimum thickness change that needs to be detected.

Penetration

The second step to assess the equipment is to determine the total linear attenuation of the part or the equivalent thickness to a known base material. This method normalizes the attenuation or thickness of the part into a single material equivalent. Figure 1 represents sample parts and shows the various materials and thicknesses that need to be accounted for in basic cylindrical designs. In the TNT billet example, only a single material is being imaged but needs to be converted into a material that is commonly used to range x-ray energy versus penetration. Typically, steel, iron, aluminum, magnesium, or titanium is used. Equation 4 provides the method to do this for a pair of materials, while equation 5 is valid for two or more materials.



(a) TNT billet | (b) Two material example | (c) Three material example

Figure1
Part configurations and materials

$$\rho_1 * t_1 = \rho_2 * t_2 \tag{4}$$

where 1 is the primary material and 2 is the secondary material.

$$Equivalent\ thickness\ (t) = t_1 + \sum_{2}^{i} \frac{\rho_1 * t_1}{\rho_i} \tag{5}$$

where 1 is the primary material and i are the materials to be made equivalent.

Once the material thicknesses (t) and the materials densities (ρ) for each piece are collected and recorded, the equivalent thickness for the inspection piece can be determined. Table 3 provides a layout of these values for the three examples shown in figure 1. Once the total equivalent part thickness is determined, the proper IQI(s) can be obtained in order to develop the technique and verify the image quality.

Table 3
Equivalent thickness of several examples shown in figure 1

	Thickness (t) (in.)	Densities (ρ) (g/mL)	ρ*t	Equivalent thickness (in.) to magnesium (1.74 g/mL)	Equivalent thickness (in.) to iron (7.87 g/mL)
TNT billet	2	1.65	3.3	**1.90**	**0.24**
Example 2 material 1 interface 1	0.25	7.87	1.9675	1.13	0.14
Example 2 material 2	1.5	1.74	2.61	1.50	0.19
Example 2 material 1 interface 2	0.25	7.87	1.9675	1.13	0.14
Total liner attenuation of example 2				**3.76**	**0.48**
Example 3 material 1 interface 1	0.5	7.87	3.935	2.26	0.29
Example 3 material 2 interface 1	0.25	1.74	0.435	0.25	0.03
Example 3 material 3	0.5	8.96	4.48	2.57	0.33
Example 3 material 2 interface 2	0.25	1.74	0.435	0.25	0.03
Example 3 material 1 interface 2	0.5	7.87	3.935	2.26	0.29
Total liner attenuation of example 3				**7.60**	**0.97**

If digital imaging media is being used [i.e., digital detector array (DDA), a linear array, flat panel, phosphor plate, etc.] additional variables have to be discussed. Otherwise, a general comparison can be made for the total equivalent material with a penetration chart to determine what range of photon energies is needed in order to sufficiently create a useable exposure. This data typically is available from the source manufacturer. An example of a general exposure chart for steel is provided in figure 2.

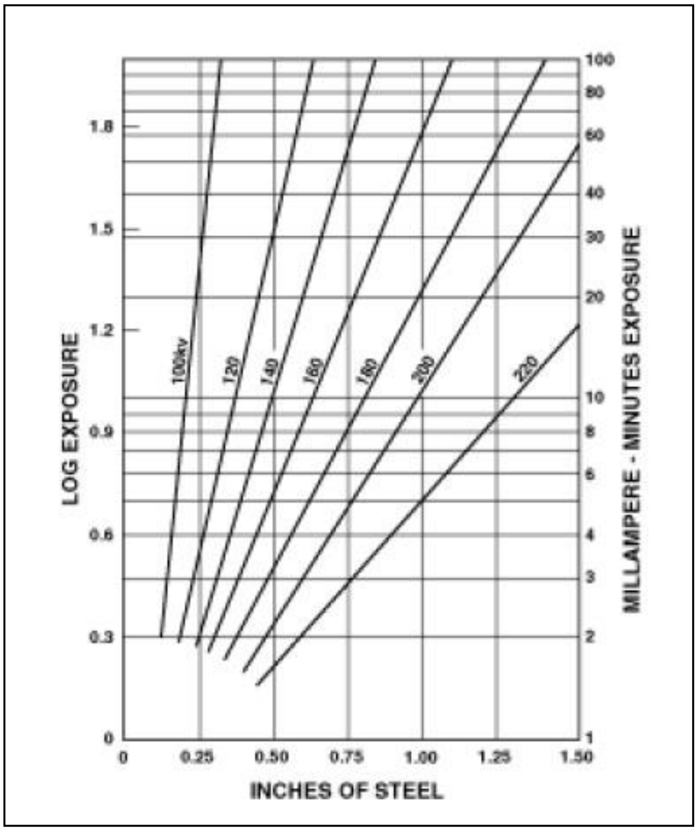


Figure 2
General exposure chart for steel equivalent thicknesses (ref. 5)

Digital Detector

Pixel Pitch

In addition to all the previous variables, digital detectors require more considerations when determining what type is needed. With respect to the geometry, the pixel width and/or pitch has to be accounted for in order to assure the spatial resolution is maintained. The three most common commercially available pixel pitches are 400, 200, and 147 µm across for rigid flat panel DDAs. Other sizes are available and vary between the types of image media available. The practitioner should understand that the pixel pitch or scanning resolution defined by the manufacturer is not necessarily indicative of better image quality. In general, pixel pitch or scanning resolution does explicitly relate to the dynamic range or achievable contrast range of the inspection piece. Just because very small indications can potentially be seen does not mean it will be detectable or reliably seen if all the other variables are not optimized to do so. Additional guides to using and understanding DDAs include ASTM E 1255, 2698, and 2597 (refs. 6 through 8).

Table 4 presents a basic comparison between the pixel pitch, the effective pixel size, and the geometric unsharpness using the same magnification and unsharpness information from table 3. The effective pixel pitch takes into account the physical magnification of the setup and is determined by equation 6. Between the unsharpness and effective pixel pitch, the larger of the two will dictate the minimum spatial resolution of the setup. Using the same examples in table 3, five of the twelve setups have the unsharpness as the driving variable. The other seven are limited by the pixel pitch and/or magnification, and not by the rest of the physical setup such as the focal spot size.

Table 4
Pixel pitch and unsharpness comparison

Effective pixel size comparison												
Pixel pitch (µm)	400	400	400	400	200	200	200	200	147	147	147	147
Pixel pitch (mm)	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.147	0.147	0.147	0.147
Pixel pitch (in.)	0.016	0.016	0.016	0.016	0.008	0.008	0.008	0.008	0.006	0.006	0.006	0.006
Magnification (x)	1.056	1.056	1.056	1.056	2.000	2.000	2.000	2.000	1.083	1.083	1.083	1.083
Effective pixel size (um)	378.947	378.947	378.947	378.947	100.000	100.000	100.000	100.000	135.692	135.692	135.692	135.692
Effective pixel size (mm)	0.379	0.379	0.379	0.379	0.100	0.100	0.100	0.100	0.136	0.136	0.136	0.136
Effective pixel size (in.)	0.015	0.015	0.015	0.015	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.005
Unsharpness (mm)	0.175	0.083	0.028	0.006	6.300	3.000	1.000	0.200	0.263	0.125	0.042	0.008
Unsharpness > pitch	no	no	no	no	yes	yes	yes	yes	yes	no	no	no

$$Effective\ Pixel\ Size = \frac{Pixel\ Pitch}{Physical\ Magnification} \tag{6}$$

Saturation

In this section, the exposure of the DDA is discussed. Depending on the detector, the inspection piece, and the general scatter that is present, the exposure can vary. In this case, the exposure is a measure of how much radiation is reaching the detector and how much each pixel is saturated. Assuming the selected x-ray energy of the inspection is fixed, the saturation will depend on how attenuating the part is, the original photon count (beam current used), and the presence of any scatter. To begin, assume the amount of scatter reaching the detector is zero. The factors that indicate if the detector is receiving adequate saturation or exposure are the total signal or dose each pixel is receiving and the available bit depth of the detector. The bit depth is defined by how many grayscale values (GV) a detector can measure or create for a given exposure. With today's current technology, most DDAs use either a 14 or 16-bit depth. The number of GVs to bit depth is shown in equation 7.

$$\#\ Grayscale\ Values = 2^N - 1 \tag{7}$$

where N is the bit depth.

For this discussion, assume the use of a bit depth of 16 or 65535 GV. What this means is that when the pixels of the DDA are fully saturated, the GV for each pixel will be 65535. For any pixels receiving less exposure, dose, or signal, the GV will be less, and for any pixel not receiving a signal, a value of 0 will occur. This, of course, can be inverted depending on the user or software settings. The level of saturation or exposure can be varied by several options including: (1) increasing or decreasing the beam current or dose rate, (2) changing the gain factor on the detector, and (3) adding or removing inline beam filtration. Other situations can affect the saturation limit of the detector like increasing or decreasing physical magnification or by manipulating gain calibrations. Those cases will not be reviewed in this report due to the added complexity of their application. From here, a practitioner should have a fixed energy setting, a fixed magnification setting, and only need to vary the beam current or dose rate to adjust to the optimized exposure level. Assuming no calibrations have been performed (i.e., bad pixel map, offset, or gain corrections), and with the part in place, the practitioner should adjust the current/dose until the background of the detector is saturated in the 70 to 85% or 45875 to 55705 grayscale range. This also assumes all the other options within the software package remain fixed as well (i.e., frame rate, etc.). In the event the current/dose cannot be adjusted to a useable saturation level, other variables can be modified accordingly, such as increasing or decreasing the acquisition time (frames per second). In some cases, the SDD may need to be increased or decreased to meet an adequate saturation range, in which case assurance must be made that the spatial resolution remains at or better than the requirement.

Once a sufficient range is met, the practitioner has to verify if the exposure through the inspection piece is adequate. References 6 through 8 provide further guidance on the required signal through the part, but generally, a good inspection should have a 10% or greater signal through the area of interest. In some cases, less can be used, and in others, a significantly higher exposure may be necessary. At this point, consider that scatter is present and is being created from the inspection piece and every other surrounding material within the exposure room, cabinet, or cell. This scatter or noise will increase the saturation on the detector for the same exposure when assuming it was not present. This added exposure or noise is any deviation the detector reads out that is not from the actual examination. Some of this noise is inherent to the detector, in which case an offset calibration is used to correct for this type of noise. Other noise created by scatter is adjusted for by using a gain calibration in which the pixels are put under exposure at different saturation points (i.e., 70 to 85%, 50%, and 20%). This allows any pixels that under or over respond to be averaged out with their neighboring pixels. This corrects for the heel effect from the source, an asymmetric beam output from the source, asymmetric response of the detector, and for scatter not attributed by the inspection piece. As with any DDA, any pixels that are nonfunctioning are corrected out using a pixel map. The practitioner should ensure that no parts or components are in the field of view when performing any of the calibrations or corrections mentioned.

Once an exposure is prepared and calibrations are completed, a quality check needs to be completed. This check verifies the detector is sufficiently saturated, an adequate signal or dose is penetrating the part and reaching the detector, and the amount of noise is not impacting the image quality requirements. With this check, the signal to noise ratio (SNR) is the primary measurement being taken. To ensure the best possible exposure, the SNR should be measured in two areas of interest, within the background and in the part under inspection. Equation 8 provides the method of determining the SNR, where the standard deviation (SD) is equivalent to the noise. This measurement, using a common histogram, should be taken over some fixed area representing the nominal exposure in the area of interest.

$$Single\ to\ Noise\ Ratio\ = SNR = \frac{Mean\ Gray\ value\ (GV)}{Standard\ Deviation\ (Std\ Dev)} \tag{8}$$

The SNR of the background, with the part in place, should conform to the minimum requirements set forth in reference 6. A SNR of 250 represents a contrast sensitivity of 1%, while a SNR of 130 represents 2%, and a SNR of 70 represents 4%. Unfortunately, this is not enough information to ensure an adequate exposure to the part itself. Ideally, the same SNR values hold when taking a measurement within the part but, realistically, are not always translatable. The area of the measurement should encompass the same materials and thicknesses for an accurate measurement. In the case of a weld inspection, the base metal can be used for the SNR measurement unless specified differently by the requirements. In the TNT billet example, the area of interest would be a measurement mainly centered on the cylindrical shape since the thickness change toward the outer diameter will affect the output. In many cases, the acceptable SNR value within the part will depend on other IQI measurements or acceptance criteria. Further discussion will be made in the image quality verification section of this report. Once a final SNR value range is determined for a given part and exposure, it can be used to provide continual assurance the image quality and exposure are meeting the requirements. Figure 3 provides a basic example of taking a SNR measurement on the TNT billet and the surrounding background. The values recorded from figure 3 are included in table 5.

(a)
Taken in the surrounding background

(b)
Taken in the TNT billet image

Figure 3
SNR measurements

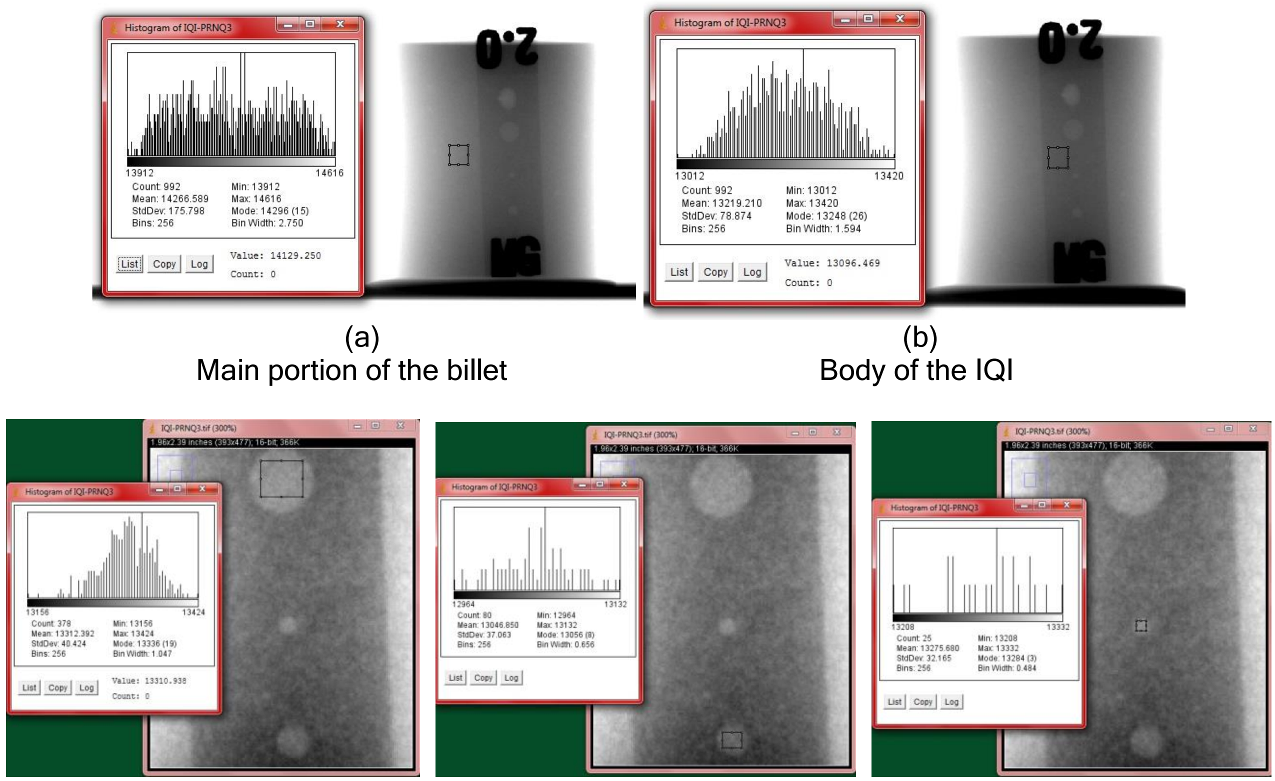
Table 5
Recorded exposure values for the TNT billet

Signal to noise ratio measurements				
	Signal/Mean (GV)	Noise/SD (GV)	SNR	
Billet background	33456.04	163.89	204.13	
Billet - center	14664.14	374.46	39.16	
Contrast to noise ratio measurements				
-	Signal/Mean (GV)	Noise/SD (GV)	CNR	Contrast sensitivity (%)
Billet - center	14266.59	175.80	-	-
IQI base	13219.21	78.87	5.96	7.92%
4T hole	13312.39	40.42	1.18	0.70%
2T hole	13046.85	37.06	2.19	1.30%
1T hole	13275.68	32.17	0.72	0.43%

Contrast

The SNR values of a given exposure are valuable measurements on the consistency of the exposure and quality of the technique; however, by themselves, they do not fully encompass how to verify image quality in a digital image. The SNR does not explicitly measure how much contrast can be seen within the part itself, and if a contrast change is present, if it will be detected. Reference 6 also provides methods to measure a contrast to noise ratio (CNR) while using a hole IQI. Generally, this provides a consistent manner in measuring the CNR, but it's not always applicable when a standard hole IQI cannot be used. When a hole IQI is not applicable, the CNR can be determined from a known defect or indication or be used as a general comparison between images to show consistent reliability. Equation 9 provides the basic method for determining the CNR between two areas of interest, two materials, or between the inspection piece and the background. In equation 9, the background can be the main material or region under examination while the region of interest (ROI) can be a void, a secondary material, or a density variation within the ROI. Basically, the CNR is a measurement of the signal changes between two ROI. Figure 4 provides a basic example of taking a CNR measurement on the TNT billet. The values recorded from figure 4 are included in table 5. Once the SNR and CNR are tallied, a comparison to the requirement can be made against the contrast sensitivity requirements with the part specification. Equation 10 provides the basic method of determine the contrast sensitivity.

$$Contrast\ to\ Noise\ Ratio\ = CNR = \frac{GV\ (ROI) - GV(background)}{Std\ Dev\ (background)} = \frac{\Delta GV}{Std\ Dev} \tag{9}$$



(a)
Main portion of the billet

(b)
Body of the IQI

(c)
4T hole

(d)
2T hole

(e)
1T hole

Figure 4
CNR measurements being taken in the TNT billet and IQI

$$Contrast\ Sensitivity\ = \frac{CNR}{SNR} = \frac{Contrast}{Signal} = \frac{\Delta GV}{GV} \tag{10}$$

Other Considerations

In addition to the tools and method described previously for digital image media, other resources, tools, and considerations should or can be taken. For further assurance of the spatial and contrast components of a digital image, a line pair gauge and/or duplex wire gauge can be used (ref. 6). These tools are similar in that they are small wires aligned in a specific fashion so that a user can determine qualitatively and quantitatively how much separation can be detected between them. In other words, how close the wires can get before the separation between them can no longer be seen or accurately measured. This value is typically provided in line pairs per millimeter (Lp/mm) or pixels per mm and is a measure of what the smallest detectable feature is. In general practice, the duplex wire gauge can be more accurate and is easier to use since a majority of existing radiographic software has tools that can expedite the calculation. There are several other devices available that can perform the same function as well, such as wire mesh phantoms, but all of them provide information as to the quality of the technique, setup, and image for a digital radiographic inspection. For an even more detailed analysis of the image quality, the modular transfer function (MTF) can be determined. This is a tool typically used to assure, verify, or measure the system, equipment or technique can accurately display or detect very sharp edges, points or interfaces that occur within an inspection piece. The determination of the MTF is generally left for highly detailed inspections such that would occur using computed tomography. The use of these tools is outside of the scope of this report and may or not be applicable depending on the requirements of the inspection. In many cases, some of these tools are used in conjunction with the process provided within these works, and are other standardized methods to determine the bounds in which the contrast and spatial components of the inspection are adequate.

IMAGE QUALITY VERIFICATION

Once the equipment is selected, and is initially verified to meet some basic requirements, the verification of the image quality can occur. This is the tangible measurement that assures all the other characteristics coincide and together meet the part specification. In the example of the TNT billet, a hole IQI was used. The IQI used matches the thickness requirement and has contrast sensitivity ranges to show if the inspection is valid, borderline, or has inadequate image quality. Figure 5 shows three comparative images of the TNT billet with and without an IQI present and with post processing digital filters applied.

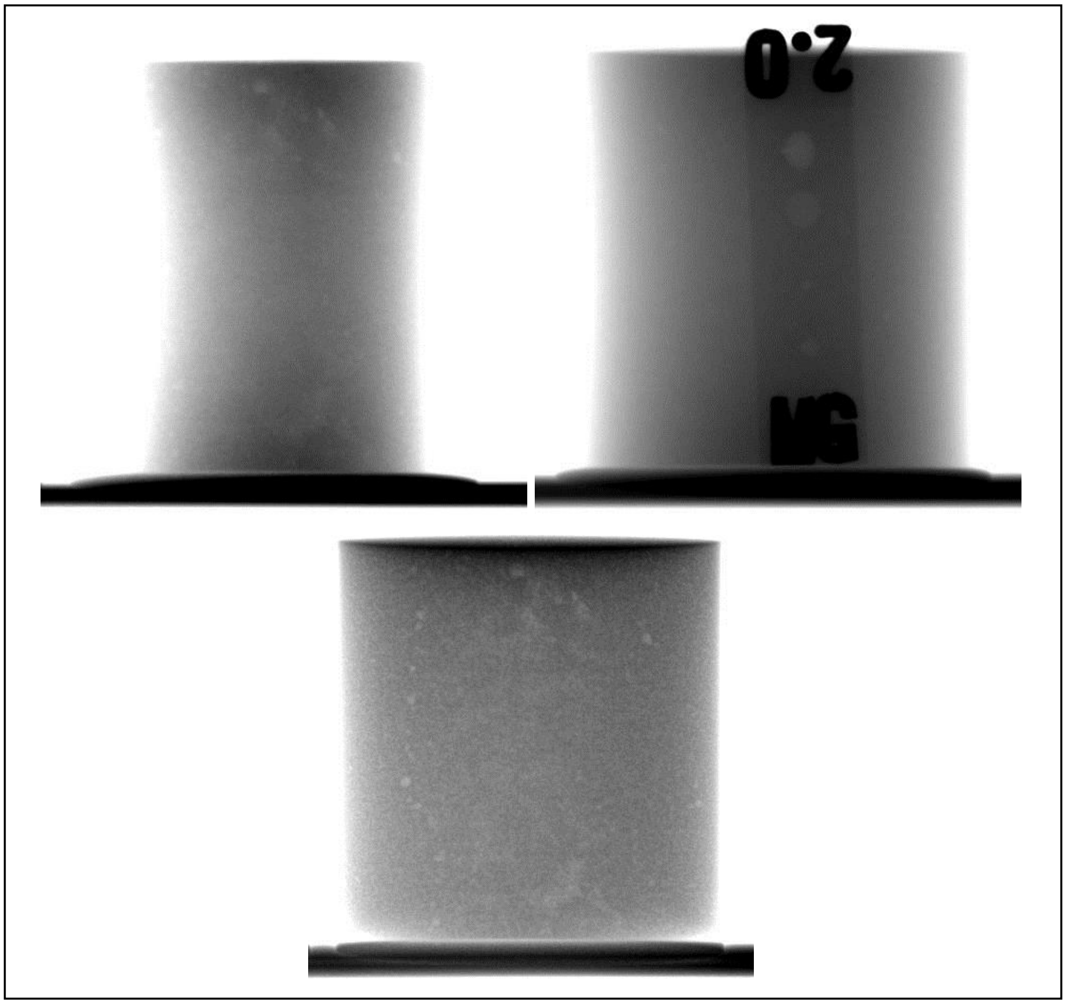


Figure 5
Radiograph of the 2-in. diameter cast billet; without IQI raw (top left), with IQI raw (top right), without IQI post-processed (bottom)

During the process of imaging the IQI, all the qualitative measurements and qualitative assessments can be made in regard to the image quality. In this case, the CNR can be measured from the IQI. In other cases, defect standards may be in use where the SNR and CNR are based off of a specified ROI within the inspection piece. For example, if there was a defect standard depicting the void criteria, the void may be the area in which the CNR is based off of in respect to the main TNT cast. The process of selecting the equipment, developing a technique, and verifying image quality may take several revisions until the inspection is acceptable. The order in which they take place may also vary too in order to find the correct setup and technique. Once in place, the process should be repeatable. In the example discussed, the image quality is only ambiguously listed as a requirement. In applying the application, image quality verification should be confirmed once the final technique is determined and at some fixed interval if production rates are being inspected. In detailed specifications, this interval may be defined as required after so many samples, after a given number of images, or over a specified interval of time. Generally, it is understood that verification occurs prior to accepting any products and once the inspection is completed. This ensures no drifts in the equipment or changes in the setup occurred in between the previous quality check.

TECHNIQUE DEVELOPMENT

The technique development is an extension of everything reviewed within the equipment selection and image quality verification sections of this report. The technique development is the stage when all of the minimum equipment requirements are known and the final optimized setup is completed. The technique is the finalized values and ranges for all the settings that can change or affect the image quality. For any given inspection, piece multiple variations of settings and variables can be used in order to achieve an acceptable image quality and inspection. Finding the compromise between the setup, the available equipment, the required quality, and throughput can be a difficult balance. For research and development applications, a highly perfected technique may be necessary when an inspection piece may be critical in nature to ensure it works as intended the first time every time. In high volume production applications, an overly detailed technique may result in a lower throughput, which may conflict with other post assembly, scheduling, or contractual needs. It is important to note that the need for higher throughput should not conflict with the purpose of performing a quality assurance step such as verification using NDT or radiography. The primary task for an NDT practitioner should always be the mindset of quality first throughput second, even when pressured. At the same time, depending on the inspection, a highly detailed inspection may not be needed if the part specification only requires the presence of large subcomponents or gross discontinuities.

An example of a detailed equipment listing and a technique sheet is provided in the "Detailed Concepts in Performing Oversight on an Army Radiographic Inspection Site" report from July 2015 (ref. 9). These examples show the general level of information that goes into proper documentation and tracking to ensure a technique and inspection are repeatable and maintain a specific level of image quality. The final technique should include everything from: (1) how the parts are orientated, (2) the fixturing used to hold them in place, (3) if inline beam filtration is used, (4) if any masking is used, and (5) if any collimation is used. Any of which may reduce the field of view, scatter, or overall extrinsic noise present in the setup.

DOCUMENTATION

Standard Operating Procedure (SOP)

Once the final technique is developed, and determined to be acceptable, the basic and detailed steps and process for completing the inspection can take place. These SOP should incorporate every task needed in order to prepare, set up, start, operate, and complete the inspection. In many cases, an overarching SOP can be broken down into smaller quality work instructions to simplify tasks for level I or II certified operators and in some cases, general technicians that may just handle the inspection pieces or do other preparation for the radiographers. Within the SOP, the part under inspection and its specifications should be listed, along with any applicable references for the procedural and safety standards used during the operation. Furthermore, any personnel requirements such as qualifications or certifications needed to fulfill the operation should also be included. In addition, the aforementioned technique sheet should be included to ensure the setup and settings are laid out and consistently repeated from one shift to another or when the equipment is used for other inspection purposes. The SOP should be detailed enough so that a common untrained person could pick up the instructions and perform the tasks in order to ensure reliability between different users. The top level SOP is one of the most important documents within the practice of any NDT method in order to maintain the same level of quality assurance from the initial approval to operate until the final inspection piece is dispositioned. Two other primary sub-components of the SOP are discussed in the next two sections: (1) the critical equipment listing, and (2) the qualification planning.

Critical Equipment Listing

The critical equipment listing is basically all the primary components of the setup that can impact or change the image quality or potentially cause a variation during the inspection process. The most common pieces include the x-ray generation system, the image media, the image quality standards and/or IQIs, the acquisition and review software(s), and the fixturing in which the inspection pieces are mounted into during imaging. Additional sub-components that may be included are specialized collimation devices, computers, monitors, calibration devices, etc. This listing should also include specific information with regard to each piece such as: (1) the manufacturer, (2) model number, (3) serial number, (4) range of settings, and (5) the exact configuration used during the inspection. This listing provides traceability in the event a component degrades, malfunctions, is repaired, or replaced throughout the inspection process. In general, even an identical replacement part may not respond the same to the approved technique and could impact the ability to achieve or maintain the requirements of the process. In the event any of these situations occur, a qualification or requalification process should be applied to verify the change(s) do not impact the level of quality assurance.

Qualification Plan

A qualification plan is a document or set of procedures that provide the process in which the entire inspection process will be proven to meet the requirements of the customer or part specification. This plan is typically a set of tasks that walk through the entire SOP, verify personnel qualifications/certifications, show that the technique is adequate, and that throughput can be met. This can entail a procedure that requires a specific number of samples to be images, reviewed and dispositioned correctly. It can generally include multiple IQI verifications at a prescribed interval, and it can also include the use of “salters” where manufactured defect standards replicate specific defective or rejectable conditions within the part and are placed into the inspection process at some random interval during the qualification. These salters can be used to verify the image quality if sufficiently maintained and the radiographers are correctly dispositioning product during the process. In more complex systems that may use automated software or processes, such as automated defect recognition, a probability of detection value can be estimated according to a fixed number of samples that are run through the system and are correctly processed or dispositioned. In addition to a qualification plan that is accomplished prior to beginning production or testing, a requalification plan should be in place to re-verify the system in the event changes are made or when any modifications to the approved procedure or equipment are performed. In general, a requalification plan can either re-reference the original plan and repeat it, or may be a smaller sample set pending the customer finds it adequate to show the functionality is equivalent after a change is made.

CONCLUSIONS

The intention of this report was to provide a basic walk through on the methodology of setting up a nondestructive testing inspection process, specific to the radiographic method. Many of the components are translatable to other methods as well, specifically, the documentation portion of this report and the record keeping of technique information. There are other methodologies and principles that can be used in setting up and verifying a technique, but this report presented a general and basic way of ensuring the intent of the inspection is met. Portions of this report covered how to correctly select equipment qualitatively, the right personnel to have in place, and how to determine if a radiographic image requirement is being met in terms of spatial and/or contrast components.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

ARDEC	U.S. Army Research, Development and Engineering Center
ASTM	American Society of Testing and Materials
c	centi-, 1E-2
CNR	Contrast to noise ratio
DDA	Digital detector array
DoD	Department of Defense
eV	electron volt
ft	feet
g	grams
GV	Gray values
in.	inch
IQI	Image quality indicator
ISO	International Standards Organization
k	kilo-, 1E3
Lp/mm	Line pairs per millimeter
M	Mega-, 1E6
m	meter
mm	millimeter, 1E-3
mL	milliliters
min	minute
MTF	Modular transfer function
NAS	National aerospace standard
NDT	Nondestructive testing
ODD	Object to detector distance
ROI	Region of interest
RDECOM	Research Development and Engineering Command
RQI	Representative quality indicator
RT	Radiographic testing
SDD	Source to detector distance
SOD	Source to object distance
SOP	Standard operating procedure
SD	Standard deviation
SNR	Signal to noise ratio
TNT	Trinitrotoluene
u	micro-, 1E-6

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